Ion source developments for stable and radioactive ion beams at Ganil

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Abstract: Since now many years, the Ganil ion source team deals with high charge state and radioactive ion beam production.
Concerning radioactive ion production, the recent results obtained, in collaboration with the ISN Grenoble group, with the 1+/n+ method drove us to develop a new concept of ecr ion source for monocharged ion production. The results of the first tests of this source are given. This new idea for the construction of ecr ion source can be applied to multicharged ion production.
Concerning the high charge state ion beam production, a new source called SUPERSHYPIE has been built that allows to increase by a factor 2 the length of the hexapole of an ECR4M source. This new concept has just been started and has produced arround 50 nAe of Ar^{17+} . The first results of this new source are presented.

Introduction

For high charge state stable ion beams and for radioactive ion, two new sources have been built with new concepts for the setting up of the magnetic configuration.
The first ion source, called SUPERSHYPIE, is an upgrade of the ECR4M source[1] and allows an increase of the plasma volume in the axial direction.
The second source called Mono1000 is dedicated to the production of monocharged radioactive ions as part of the 1+/n+ program.

1 The SUPERSHYPIE ion source

1 a) description

The idea of the upgrade of our ECR4M ion source[1] consists in changing the length of the plasma by applying the SHYPIE[2] principle that consists in associating permanent magnets with coils to define the axial magnetic field. The axial permanent magnets (with a radial magnetization) create a modulation of the field that increases the maxima B given by the coils.

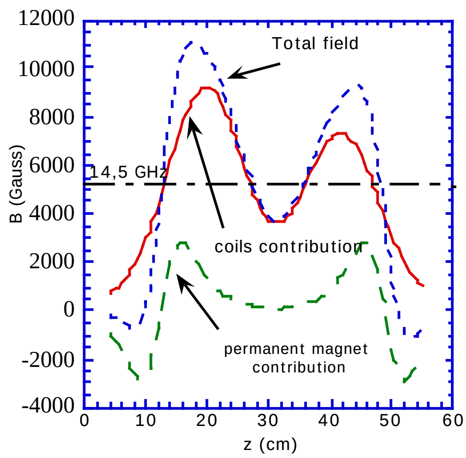

Figure 1: Axial configuration of the magnetic field of SUPERSHYPIE with 1200 A in the injection coil and 900 A at the extraction.

Thus, the 12 cm long at injection and 9 cm long at extraction iron pieces of ECR4M that concentrated the magnetic flow delivered by the coils have been removed and replaced by two 5 cm long permanent magnet rings and two hexapolar rings have been added in the free places (see figure 2).

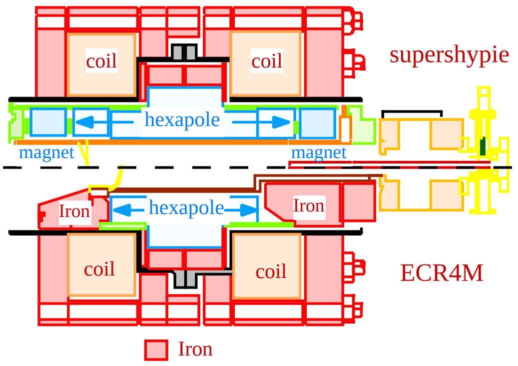

Figure 2: drawing of ECR4M and supershypie.

This has allowed the increase by a factor 1.5 of the length of the hexapole. The design of the plasma chamber has been considerably simplified as it is now constitued of a double wall cylinder.

1 b) experimental results

The source has been tested with our existing 14.5 Ghz transmitter. Figure 3 shows the charge state distribution of Helium when the source is tuned to optimise He^{2+}.

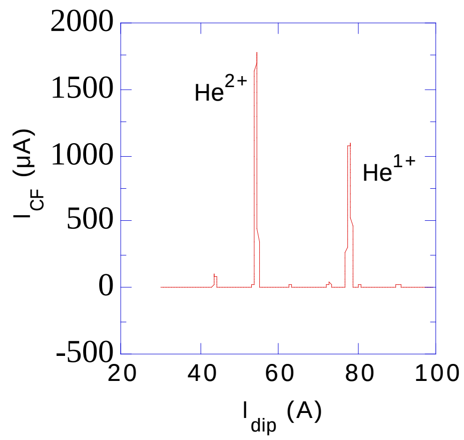

Figure 4: He spectrum optimised for He^{2+} production. P_{HF}=600W, extraction voltage=15 kV.

It can be pointed out from this picture that the electrical intensity is peaked on the 2+ charge state with 45% of the atoms in this ionisation state.
Different tests have been performed for high charge state of argon production. On figure 5 is shown a spectrum optimised for Ar^{12+} production.

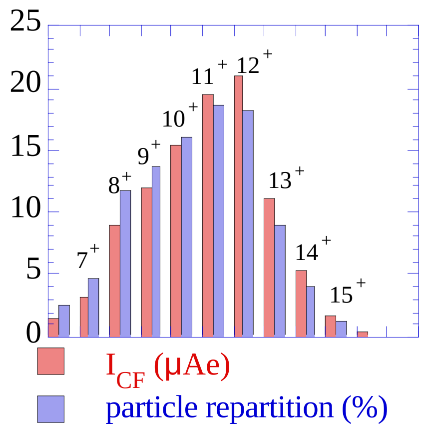

Figure 5: Argon charge state distribution when the source is optimised for Ar^{12+} production. P_{HF}=1060 W, extraction voltage=18 kV.

In this case the maximum electrical current is peaked on the 12+ charge. The particle repartition represents the percentage of the particles of argon in a given charge state compared to the sum of particles arrived in the faraday cup:

$$R = \frac{\frac{I^{q+}}{q}}{\sum_q \frac{I^{q+}}{q}}$$

this repartition shows that more than 35% of the particles are collected in the 11+ and 12+ charge states.
At least, the current of Ar^{17+} has been measured. For atomic physic experiments, the beam is sent through two 2mm diaphragms on a faraday cup connected to a picoamperemeter. The intensity of the Ar^{17+} beam measured at this point was 1 nA. By only changing the magnetic rigidity of the line, 20 nA of Ar^{16+} was measured at the same place that gives a factor 20 between the abundance of these two charge states.

As 0.9 μA of Ar^{16+} have been measured on a faraday cup located before the diaphragms at the image point of the dipole, it can be deduced that arround 50 nA of Ar^{17+} was produced if we assume that the transmission is independent of the charge state.
To check the validity of this hypothesis, the slits located before the faraday cup have been closed and the current of different charge states have been measured before and after closing the slits. It can be seen in table 1 that between Ar^{11+} and Ar^{16+} the transmission is quite independent of the charge state.

Q	11+	12+	13+	14+	16+
OS	70	54	29	14	0,66
CS	5,7	4,4	2,9	1,3	0,07
T (%)	8,1	8,1	10	9,3	10,6

table 1: Transmission (T) of different charge states of argon when the slits are opened (OS) or closed (CS) at 1 mm.

2) Mono1000: a monocharged ion source for radioactive ion beam production.

As the amount of radioactive atoms, created by the interaction of the high energy heavy ion ganil beam with a thick target, is very low (between 10 and 10^8 particle per second), the ion source must be as efficient as possible.
In the 1+/n+ program[3], atoms are ionised only once before injection inside an ecr charge booster. Thus a new monocharged ion source has been developped with the constraints of low cost, small size, high reliability, high efficiencies and low emittance.

2 a Description of the source.

The magnetic structure is made with two axially magnetised permanent magnets rings that allows to create a closed 2000 Gauss surface at the wall of the plasma chamber (see figure 6). The plasma electrode is located in a 1800 Gauss magnetic field.

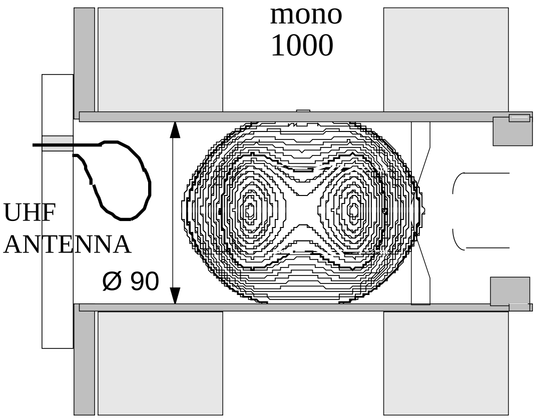

Figure 6: artistic view of the mono1000 ion source.

It has to be pointed out that no radial structure is used and that the magnetic field in the extraction area presents a cylindrical geometry.

A 2.45 Ghz UHF wave is injected into the large diameter (90 mm) cylindrical plasma chamber through a coaxial transition ended by an antenna.

2 b First results

The first tests of the source have been run with Argon and Helium with ionisation energies varying from 16 to 25 eV. The pressure inside the source was arround 2 10^{-6} mbar and the injected HF power did not exceed 20 W.
The source has been tuned with different plasma electrode hole diameters. The results of the maximum currents I, transmissions (T) between the source and the faraday cup located after the analysing magnet and current densities (J) are reported in table 2.

D	2	5	7,5
I Ar^+	0,051	0,238	0,50
T(%)		86	82
J Ar^+	1,62	1,41	1,38
I He^+		0,56	1,0
T(%)		87	53
J He^+		3,28	4,27

Table 2: Effect of the plasma electrode hole diameter (D in mm) on the Ar^+ and He^+ currents (I), transmissions (T) and current densities (J). I and J are respectively given in mA and mA/cm^2. J is corrected of the transmission.

The ionisation efficiency of the source has been measured with Ar by injecting the gas through a 36,5 μAp calibrated leak and tuning the source with He as support gas. The spectrum of the source is shown in figure 7.
The transport efficiency (T) obtained with the ratio of the sum of the currents measured in the spectrum divided by the extracted beam current delivered by the high voltage power supply was in this case arround 68%.
The ionisation efficiency (E_i) for each charge state is given by the following formula: $E_i^q = \frac{I^q}{q.T.\varphi}$ where I^q is the electrical current of the charge state q, T the transmission and φ the injected flux of atoms (36,5 μAp in our case).

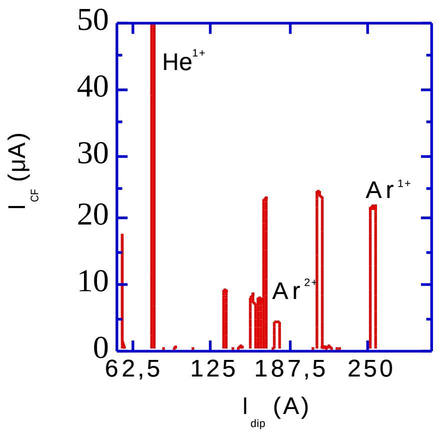

figure 7: Argon spectrum with a calibrated leak. Extraction voltage= 14 kV, extracted beam current=0,749 mA.

By this way, 90% of the injected atoms have been singly ionised and 9% of them have been obtained in the 2+ charge state.
The emittance of Ar^{+} beam has also been measured (see figure 8). It can be seen that the geometric emittance is low (30 π.mm.mrad) and that the aberations are low.

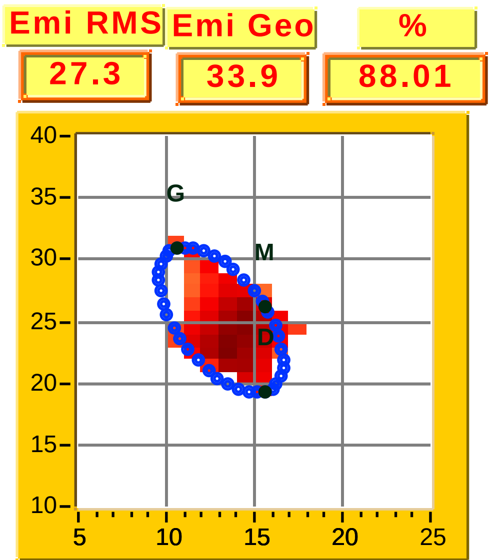

Figure 8: Emittance figure of Ar^{+} beam. Extraction voltage=14 kV, Einzel voltage=7kV, plasma electrode hole diameter=9 mm.

3 Future tests

Different tests will be performed during the next monthes. The first one will consist in studying the behaviour of Mono 1000 for condensable element production.
In the next future, the source will be sent to ISN Grenoble for 1+/n+ tests before being coupled to a target and tested at Ganil for radioactive ion beam production.
It has also to be noticed that the current prototype has been built with old magnets. A new version called mono300 has been calculated and allows to decrease the price by a factor 2 and the weight by a factor 3.
Another calculation shows that it is possible to increase the magnetic field up to 7000 Gauss on the walls with a 5800 Gauss closed surface (see figure 9) and permits the use of high frequency transmitters (10 GHz). A prototype of this source called GI 2000 will be built during the year to test the production of multicharged ions with this new concept.

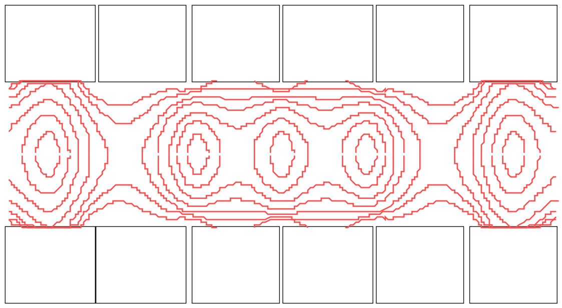
Figure 9: Schematic view of GI2000. Each line corresponds to 1000 Gauss increment.

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3 N. Chauvin et al, presented during this workshop.